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Measuring Parameters of Large-Aperture Crystals used for Generating Optical Harmonics

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Nonrefereed Report

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Measuring Parameters of Large-Aperture Crystals used for Generating Optical Harmonics

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Optical harmonic generation has long been known as a very effective means for extending the operating wavelength range of high-peak-power lasers. Generating optical harmonics in laser systems such as the National Ignition Facility (NIF), Inertial Fusion Energy (IFE) lasers such as Mercury, or lasers for isotope separation requires careful control of several parameters. Efficient transfer of power from the input beam to the harmonic beam requires the input and output waves to be phase-matched; this is most often done by using the birefringence of a nonlinear optical crystal to cancel the effects of dispersion.

The purpose of this project was to develop tools for understanding the influence of crystal quality and crystal mounting on harmonic-generation efficiency at high irradiance. Measuring the homogeneity of crystals interferometrically, making detailed physics calculations of conversion efficiency, performing finite-element modeling of mounted crystals, and designing a new optical metrology tool were key elements in obtaining that understanding.

For this work, we used the following frequency-tripling scheme: type I second-harmonic generation followed by type II sum-frequency mixing of the residual fundamental and the second harmonic light. The doubler was potassium dihydrogen phosphate (KDP), and the tripler was deuterated KDP (KD*P). With this scheme, near-infrared light (1053 nm) can be frequency tripled (to 351 nm) at high efficiency (theoretically >90%) for high irradiance (>3 GW/cm^2).

Spatial variations in the birefringence of the large crystals studied here (37 to 41 cm square by about 1 cm thick) imply that the ideal phase-matching orientation of the crystal with respect to the incident laser beam varies across the crystal. We have shown that phase-measuring interferometry can be used to measure these spatial variations. We observed transmitted wavefront differences between orthogonally polarized interferograms of $\lambda/50$ to $\lambda/100$, which correspond to index variations of order 10^{-6}. On some plates that we measured, the standard deviation of angular errors is 22-23 μrad (see Fig. 1); this corresponds to a 1% reduction in efficiency.

Because these conversion crystals are relatively thin, their surfaces are not flat (deviate by ±2.5 μm from flat). A crystal is mounted against a precision-machined surface that supports the crystal on four edges. This mounting surface is not flat either (deviates by ±2.5 μm from flat). A retaining flange presses a compliant element against the crystal. The load thus applied near the edges of the crystal surface holds it in place. See Fig. 2. We performed detailed finite-element modeling to predict the resulting shape of the mounted crystal. The prediction agreed with measurements of mounted crystals.

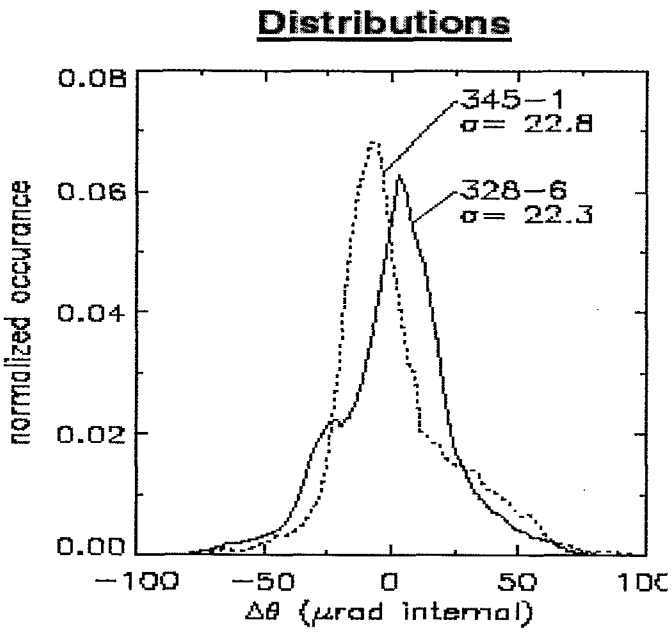


Fig. 1. A histogram of the angular errors in crystals, estimated from orthogonally polarized interferograms, is shown above. Two crystal are shown (designated 345-1 and 328-6). The histogram is number of occurrences in the interferogram file vs. angular error. The standard deviation of the distributions is 22-23 μrad.

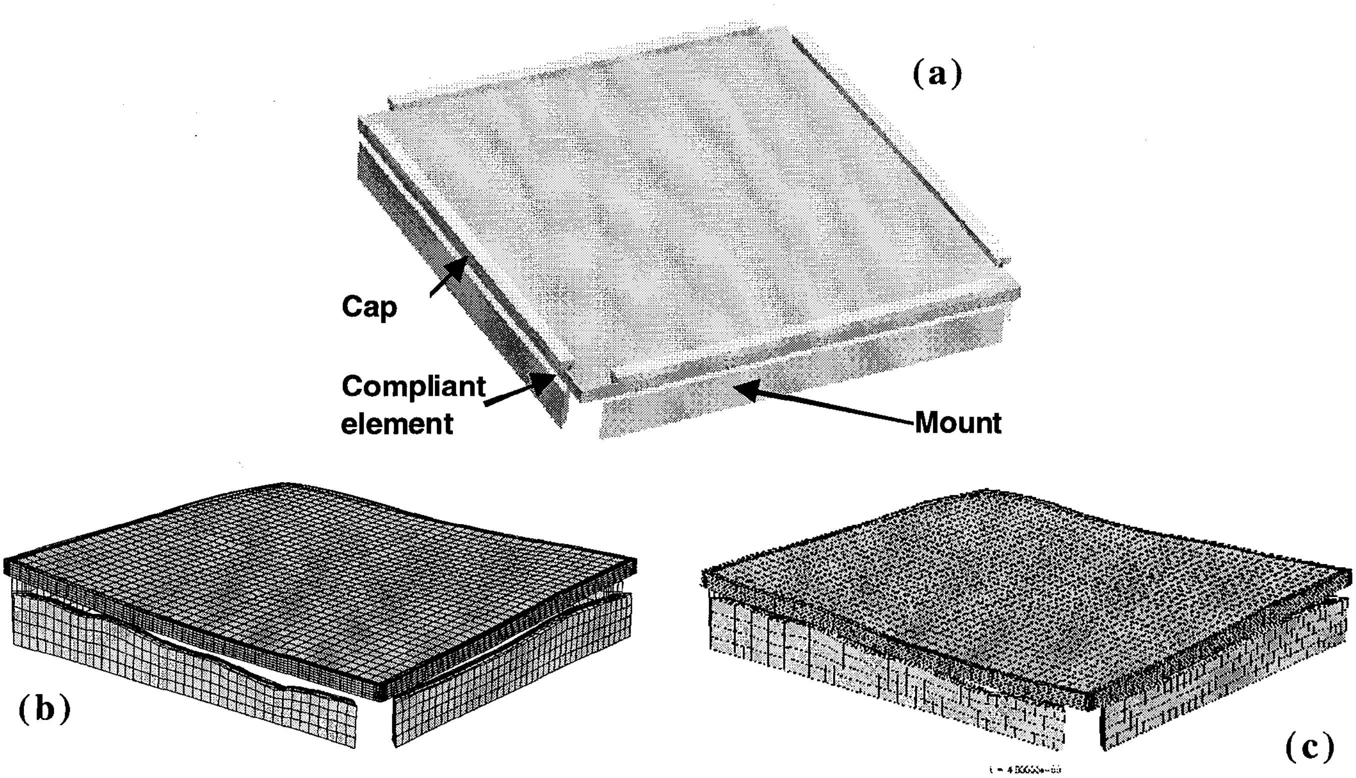
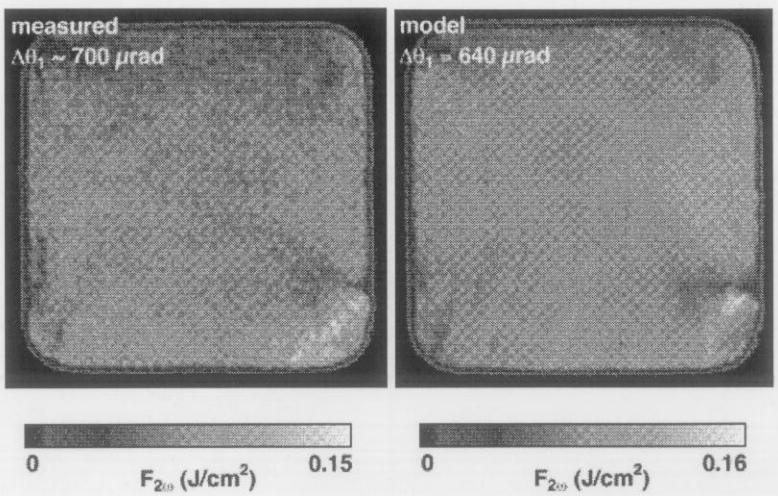


Fig. 2. The retaining flange (or cap) presses a compliant element against the crystal mount (a). The non-flat crystal is shown in a non-flat mount before applying the load (b). Finite element analysis was used to accurately predict the resulting shape of the mounted crystal after the load was applied (c).

We computed the physics of the frequency-conversion process to better quantify the effects on efficiency of variation in the crystal's axis, changes in the shape of the crystal, and mounting-induced stress. We were able to accurately predict the frequency-conversion performance of 37-cm square crystals on Beamlet, a one-beam scientific prototype of the NIF laser architecture, using interferometric measurements of the mounted crystals and the model. In a 2ω measurement campaign, the model predicted 64.9% conversion efficiency; 64.1% was observed. When detuned by 640 μrad, the model and measurement agreement is even better (both were 10.4%). See Fig. 3.



2ω energy efficiency

Δθ μrad	measured %	model %
0	64.1	64.9
340	42.8	41.5
640	10.4	10.4

Fig. 3. Shown above left (labeled measured) is a near-field measurement of the 2ω irradiance for a laser shot detuned 700 μrad from ideal phase matching. The predicted near-field (labeled as model) was computed from interferometric measurements of mounted crystals, then detuned 640 μrad. The comparison between the two is quite favorable. The table at right of the figure compares the observed energy efficiency with the predicted values.

Finally, we completed the design and initial testing of a new optical metrology tool to measure the spatial variation of frequency conversion. This system employs a high-power subaperture beam from a commercial laser oscillator and rod amplifier. The beam interrogates the crystal's aperture by moving the crystal horizontally on a translation stage and translating the laser beam vertically on an optical periscope. Precision alignment is maintained by means of a full-aperture reference mirror, a precision-machined surface on the crystal mount, and autocollimators (the goal for angular errors is 10 μrad). The autocollimators track the mounting angle of the crystal and the direction of the laser beam with respect to the reference mirror. The conversion efficiency can be directly measured by recording 1ω, 2ω, 3ω energy levels during the scan and by rocking (i.e., tilting) the crystal mount over an angular range. A photograph of the hardware is shown in Fig. 4.

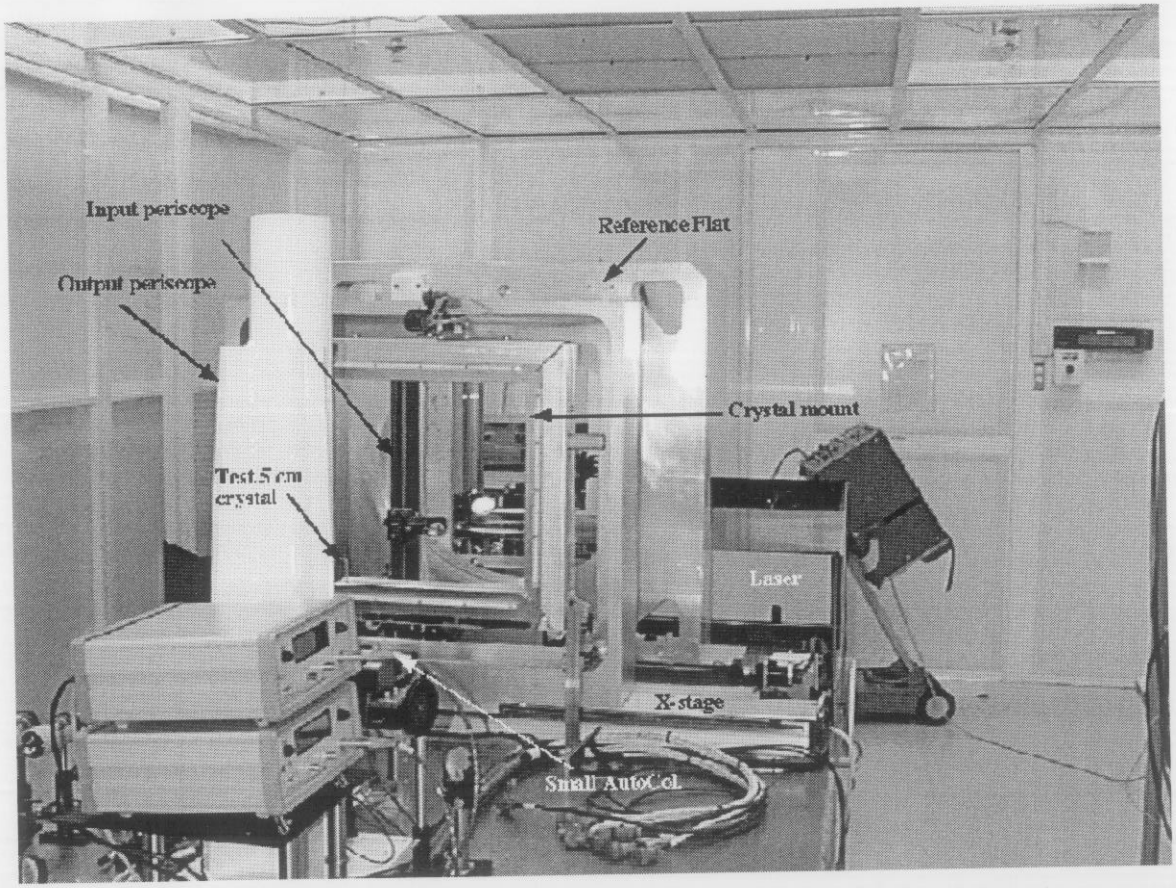


Fig. 4. A high-power subaperture beam from a commercial laser is used to measure the local frequency conversion efficiency. The crystal mount can be translated horizontally; the laser beam can be translated vertically. Autocollimators monitor the angle of incidence of the laser beam on the crystal during a scan. This angle control combined with energy measurement provides for accurate measurement of the phase matching angle.

Publications

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